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Semi-Annual Technical Report No. 2

T-6142-5

ANALYSIS OF LOW LATITUDE D AND E REGION DATA

Prepared by

Robert D. Sears

of

IIT RESEARCH INSTITUTE
Chicago, Illinois 60616

"Research Sponsored by the Advanced Research Projects Agency (ARPA Order No. 749) through the Office of Naval Research, Contract No. N00014-66-C0030, Task No. NR 088-029"

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FOREWORD

This is the second semi-annual technical report covering research performed under Office of Naval Research Contract No. N00014-66-C0030, ARPA Order 749, entitled "Analysis of Ionospheric Data". The contract period being covered is May 15, 1966 to November 15, 1966. The contract is under the technical cognizance of Mr. R. Gracen Joiner of ONR and Lt. Col. J. Hill of ARPA.

During this report period the individual analytical tasks described in the previous technical report which contribute to the analysis of ionogram data, high frequency phase and amplitude data, and cosmic noise absorption data were continued. The use of analyzed data in constructing an ionospheric electron density profile model for selected data intervals was initiated. This report mainly consists of a description of the verification of the ionospheric model for ionospheric profile change at dawn for the days 15 to 19 October 1962. One day, 18 October, is selected to show the detailed agreement of the ionospheric electron density profile obtained with true height analysis of ionogram data.

The author wishes to thank Mr. J. W. Wright of ITSA who furnished the true height analyses of the ionogram records utilized in this report.

Respectfully submitted,
IIT RESEARCH INSTITUTE

Robert D. Sears

Robert D. Sears,
Senior Scientist-Group Leader

APPROVED BY:

W O Davies
William O. Davies
Assistant Director
Geophysics Division

ABSTRACT

A technique for determining the electron density profile in the E-region from group path, phase path, amplitude and true height analysis data is described. A selected data period, 1600 to 2100 GMT on 15 to 19 October, is summarized in the detailed reduction and analysis of the individual data obtained from the different measurement techniques. One period of detailed electron density profile computation is presented. The period 1700 to 1800 GMT on October 1962 also included a moderately intense solar flare so that the excess ionization caused by the flare in the lower ionosphere may be observed. The true height analyses which are developed are extensions of the true height analyses of the F-region and serve to extend conventional true height analysis to lower altitudes or lower electron densities than possible from the conventional analyses alone.

The data were obtained utilizing ionosondes, a three frequency HF propagation measurement of both phase and amplitude and riometer measurements of cosmic noise absorption. To develop the profiles presented herein, the group height records from ionograms and phase height measurements from the HF experiment were used.

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ANALYSIS OF LOW LATITUDE D AND E REGION DATA

I. INTRODUCTION

The analysis of high frequency phase and amplitude measurements in conjunction with ionogram group path and true height electron density profile analyses was continued for the data obtained at Tongatapu and Tutuila in the spring and fall of 1962. The goal of the analysis is to better define the electron density profile at low altitudes, at electron densities and altitudes at which the conventional true height electron density profile analyses are inadequate, and to determine the short term variations in the density profile in the 80 to 120 km region of the ionosphere. The latter data is intended to furnish information on the time scale of short term phase and amplitude disturbances originating in this region. In order to define short term disturbances, the average profiles must be determinable. This effort comprised the first phase of the research effort, which extended over the first year of the contract.

Analysis of high frequency phase and amplitude data and ionograms in terms of phase path, integrated electron content, and group paths which are related to an identifiable propagation mode (eg 1 hop F mode, 0 or X wave) was initiated in the first semi-annual reporting period. The methods of analysis are outlined in the first semi-annual report on the contract. The

research effort in the second semi-annual reporting period consisted of the selection and analysis of data from a typical five day period, the dawn (1600 to 2100 GMT, 0500 to 1000 LT) for the days October 15 to 19, 1962. Because of the bulk of the analyzed data, only a small selection is presented herein. The true height curves for this data will be presented in the next semi-annual report. A shorter period of time, 1700 to 1800 GMT on October 18th, was selected to represent the progress in true height analysis for a case of one of two solar flares which was observable from the low latitude sites. The profile changes and gross effects on the individual data were clearly discernible from background; hence an interesting test (and somewhat applicable sample perturbation) is obtained for the analysis.

A number of electron density profiles are presented for the period immediately after the flare. A variation of some of the parameters of the analysis demonstrates, but does not quantitatively evaluate, the range of accuracy of the analysis. In order to evaluate quantitatively the analysis of electron density profiles, it will be necessary to compare electron density profiles computed from ionospheric models, and those computed in this analysis with in-situ measurements. Work will continue in the next semi-annual contract period to determine more electron density profiles, and to compare them with independently obtained results such as the ionogram true height analyses and other input.

Upon initiation of the second phase effort, the description of short term variations in the electron content and profile in the lower ionosphere has taken place, in that short term (minute scale) variations which are shown in data have been reduced. More data analyses in the next reporting period will show the statistical characteristics of the phase and amplitude changes and hence the electron content or profile variations.

II. DATA ANALYSIS

A. F-Region True Height Analysis

In order to provide detailed confirmation of an ionospheric model a time series of ionograms was analyzed for the dawn period (1700-1800 GMT) on 13 October 1962 using the method of Paul and Wright.(1) These analyses were carried out at ITSA by the Wright group. Figure 1 illustrates the series of true height profiles obtained for this period, and Figure 2 illustrates some of those obtained for the dawn period on 16 October 1962 at the same site, Tutuila.

The electron density profile above the F-region peak was extended as described in the first semi-annual technical report(2) by adoption of a constant scale height Chapman layer fit to the peak of the true height analysis curves.

The absorption variation for the dawn period of 18 October 1962 was computed using the formulation described in the previous report, for which

$$\text{Abs (30 MHz, db/km)} = 4.6 \times 10^4 \, N_e \, \nu_{ei} / (\omega^2 + \nu_{ei}^2) \quad ;$$

the temperature dependent electron-ion collision frequency is given by

$$\nu_{ei} = 1.8 \, N_e \, T_e^{-3/2} \ln (1.54 \times 10^8 \, T_e^3 / N_e) \quad .$$

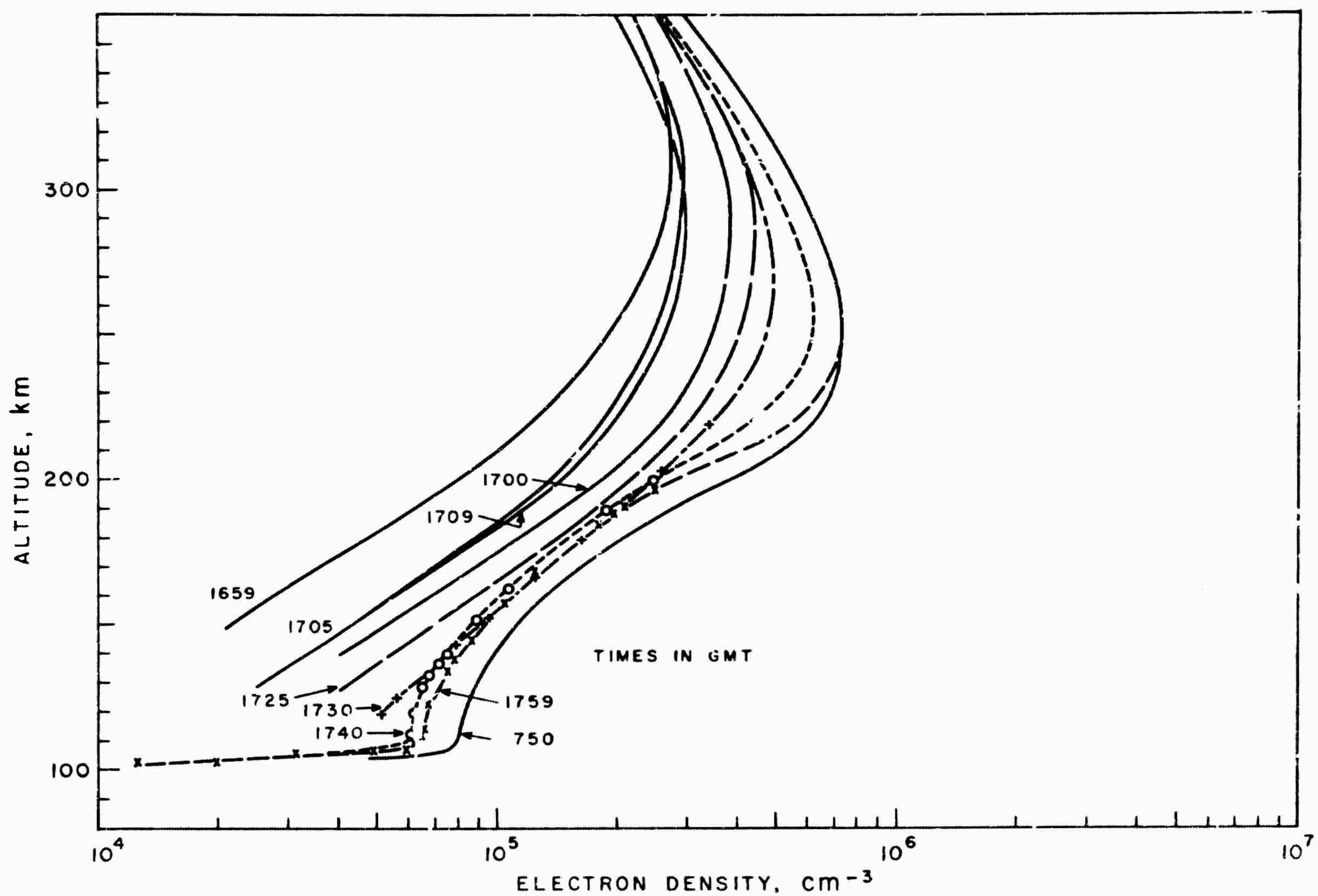

FIG. 1 TRUE HEIGHT ANALYSES FOR 18 OCTOBER 1962, TUTUILA. DAWN PERIOD.

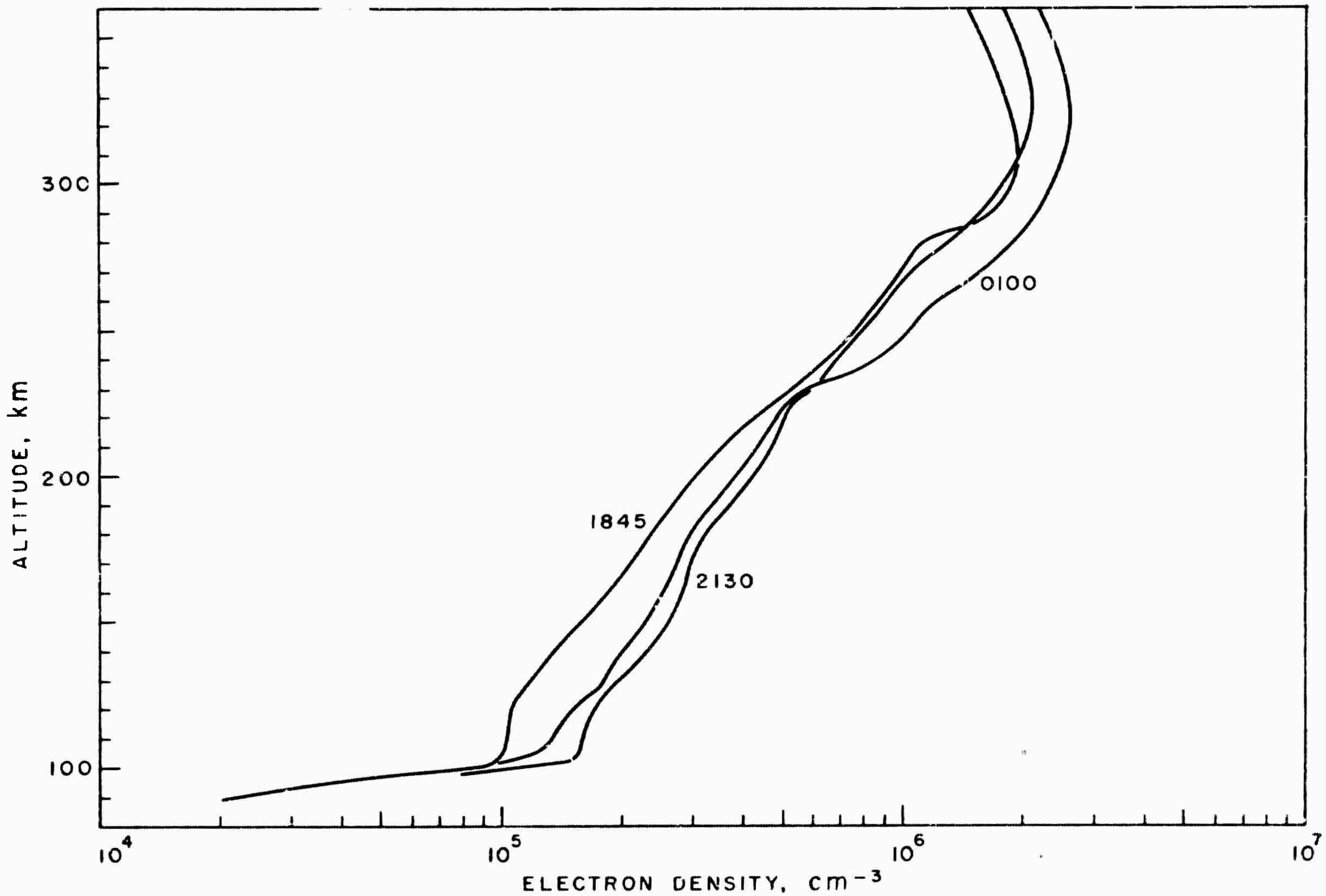

FIG. 2 TRUE HEIGHT ANALYSES FOR 10 OCTOBER 1962, TUTUILA

In this case the electron temperature is assumed to be equal to the ambient temperature, in which case the computed absorption is a maximum.

B. Determination of Group Path from Ionograms

Ionograms from the dawn period, 1600 to 2100 GMT for the interval 15 to 19 October 1962 were reduced to a virtual oblique group path format by the technique of Smith[3] described in the first semi-annual report. This reduction was carried out for the F propagated modes of both magneto-ionic ordinary and extraordinary and high and low ray cases. The frequencies used were 4, 6 and 9 MHz and the propagation path was from Tongatapu to Tutuila. In order to best describe the growth of the E-region and upper D-region during the dawn period, only the F modes were selected since they pass through the lower ionosphere largely in a non-deviative manner.

The results of the five-day dawn effect reduction effort are illustrated by Figure 3, which comprises the data for 19 October 1962. The oblique group path is presented in kilometers versus time for each mode and for each ray path when appropriate. Two distinct modes of behavior are present. The ray path often is not established on either ordinary or extraordinary traces on the higher frequencies. Therefore, as soon as the path is established, the virtual path length decreases rapidly as the reflection point is lowered on the developing F-region density

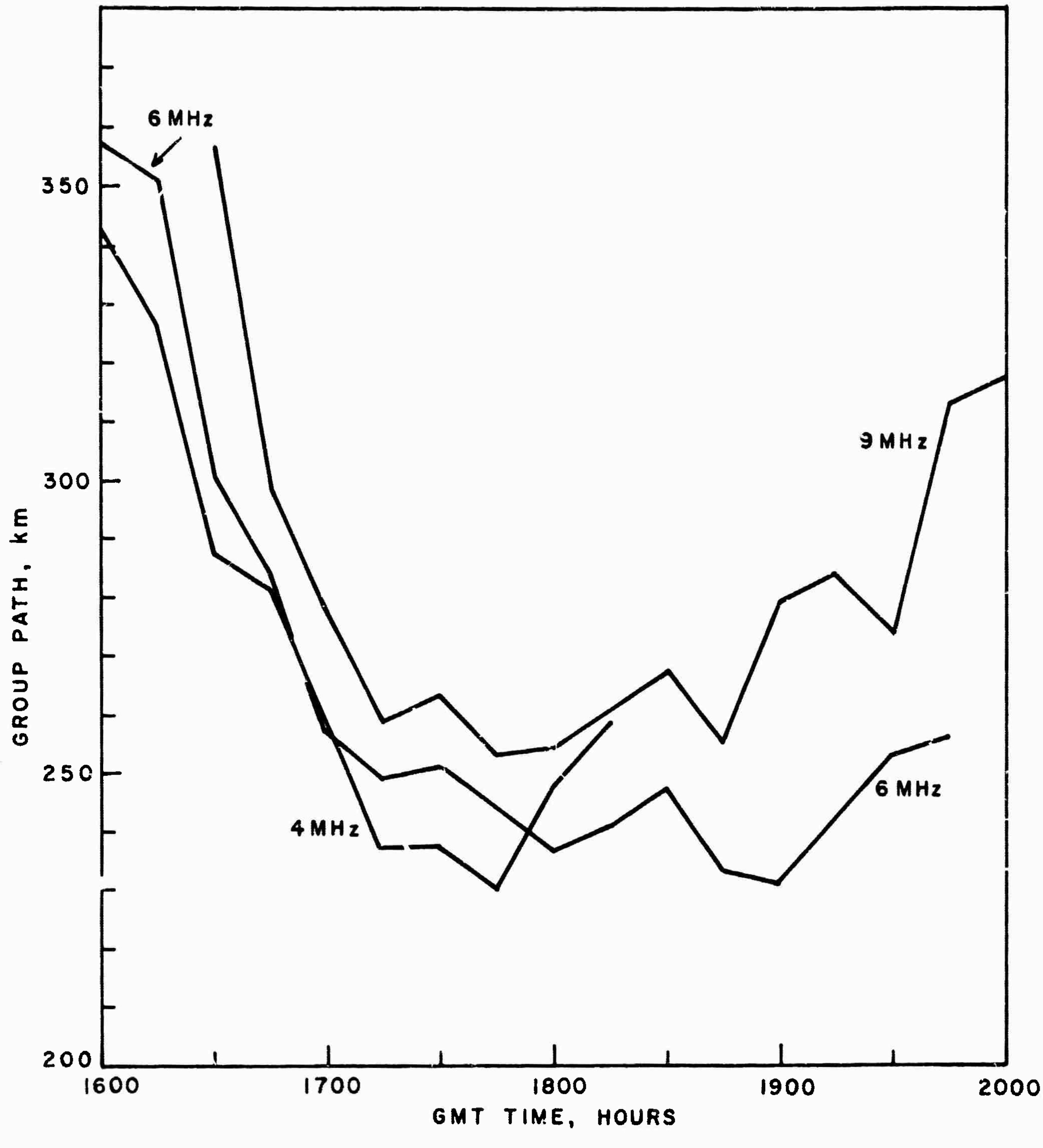

FIG. 3 O-WAVE GROUP PATHS, F-MODE
1600 - 2100 GMT
19 OCTOBER 1962

profile. Sometime after the dawn at E-region altitudes, the virtual height on all paths is raised once more as the increasing ionization causes retardation of the waves. This effect is inversely proportional to frequency and the lower frequency F-modes are lost first.

In order to confirm the ionospheric electron density profile model by comparison with detailed true height curves obtained from ionogram analysis, a short period at dawn on the 18th of October was chosen for a detailed intensive time study. The group paths for this period are shown in Figure 4.

In the case of both the longer term dawn effects and the intensive study, the virtual group paths are converted into apparent Doppler frequency formats so that they may be directly compared with the HF data in the analysis. In addition, the Doppler is integrated from a given starting time in order to give the relative phase path change from that time; this process also tends to smooth the otherwise large short term variations in the Doppler caused by the ± 2 km error of reduction of the ionogram records.

The results of this conversion are illustrated in Figure 5 for the 19 October dawn study data and in Figure 6 for the detailed analysis of the data for the 18th.

C. High Frequency Phase Paths

The description of the separation of the modes of propagation into F-region and E-region modes as outlined in the

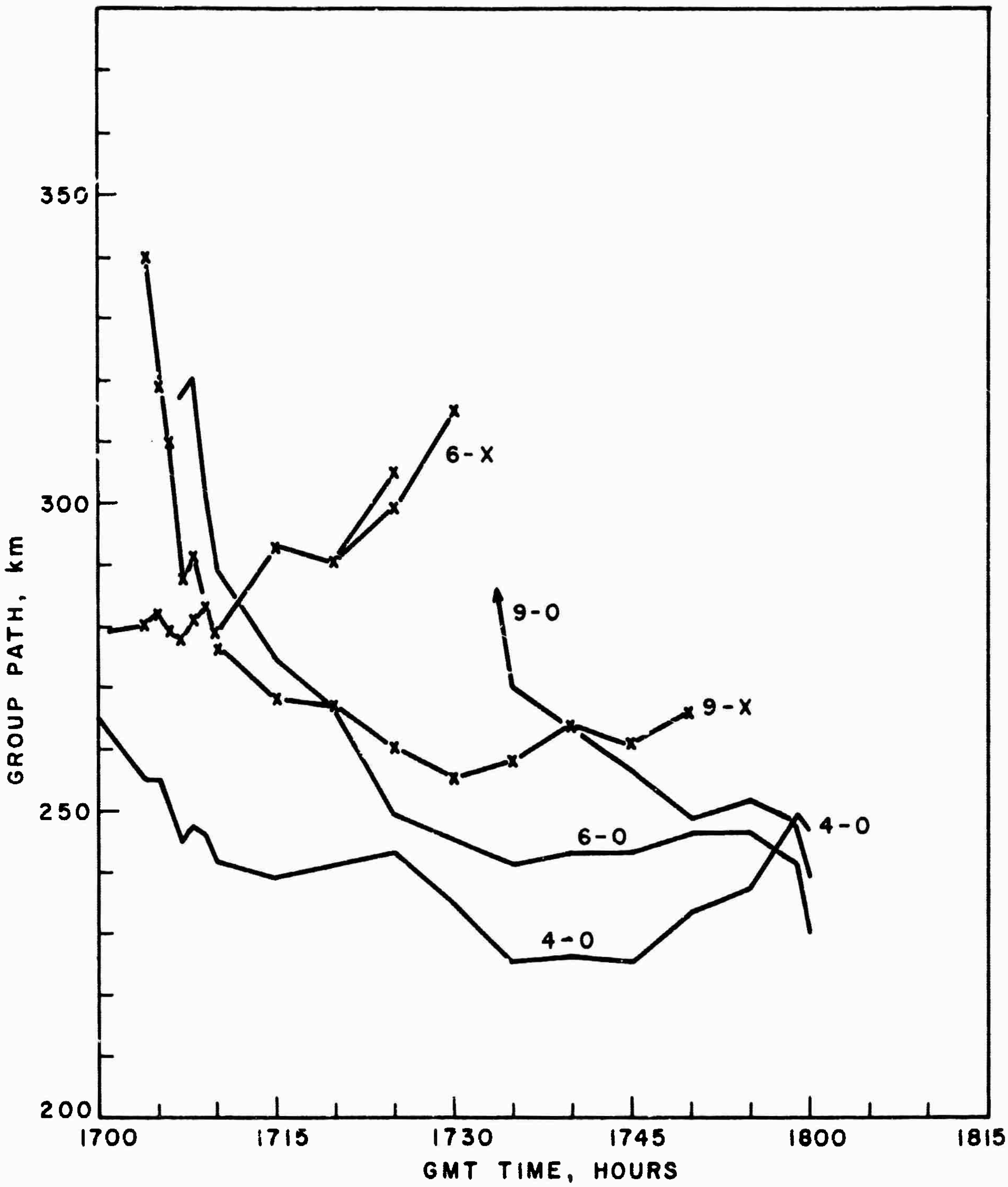

FIG. 4 OBLIQUE GROUP PATHS, F-MODE
TUTUILA IONOGRAMS
1700-1800 GMT
18 OCTOBER 1962

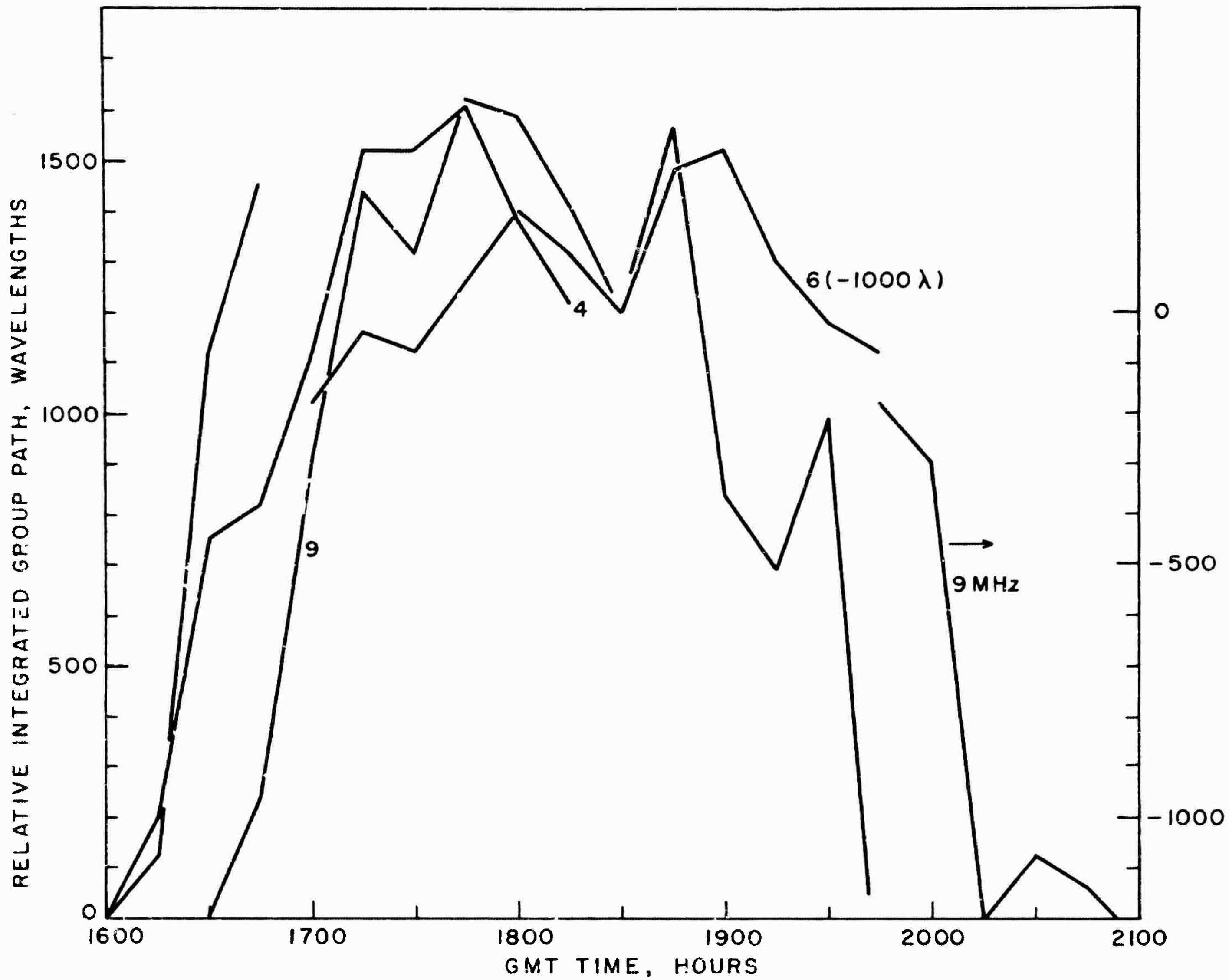

FIG. 5 INTEGRATED GROUP PATHS, F-MODE
1600 - 2100 GMT
19 OCTOBER 1962

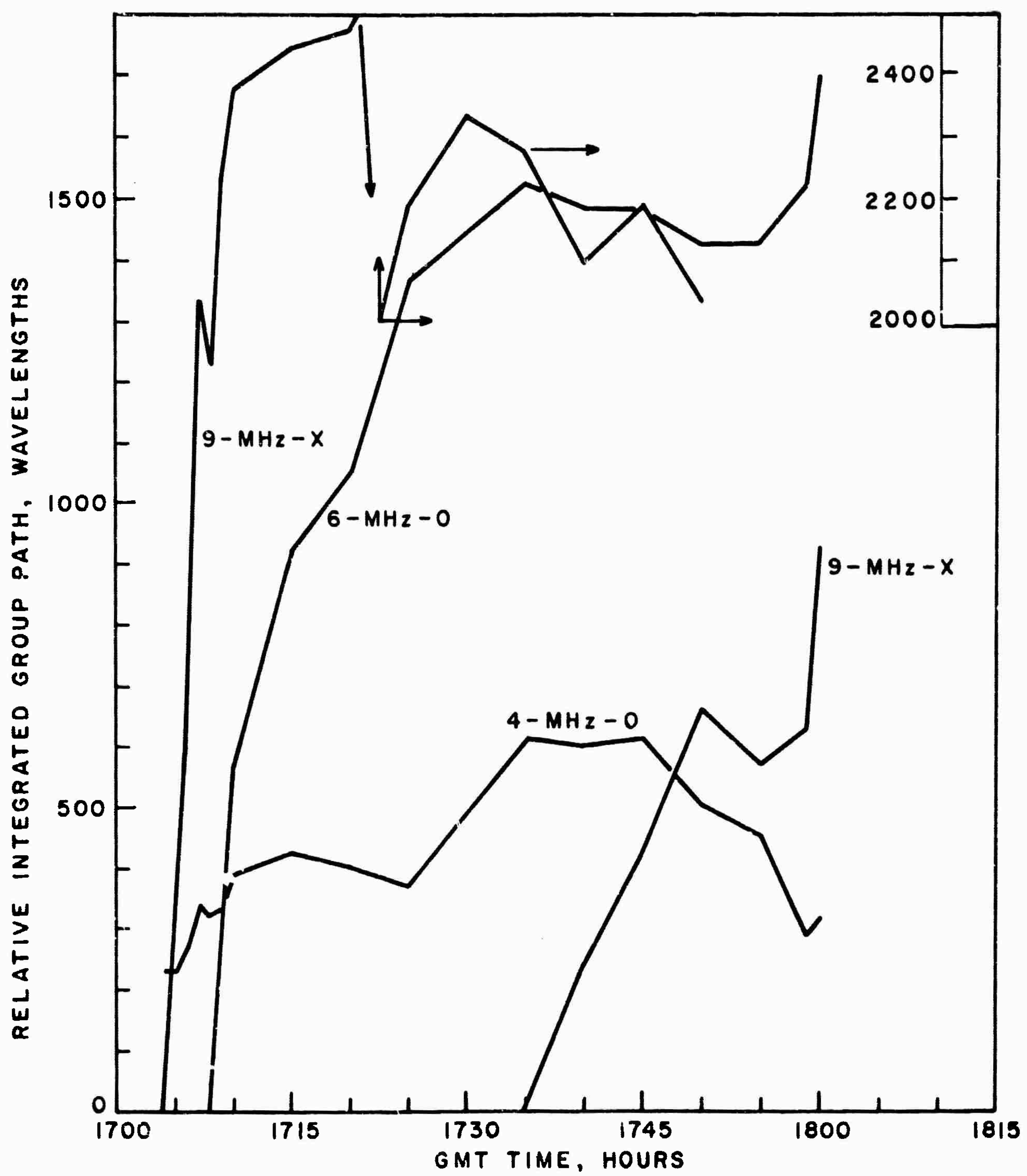

FIG. 6 INTEGRATED GROUP PATHS, F-MODE
1700-1800 GMT
18 OCTOBER 1962

previous semi-annual report was followed in order to determine the changes in the F-mode phase path lengths for the dawn periods on 15 to 20 October 1962 and, in addition, for the detailed analysis period of 1700-1800 GMT on 18 October. Examination of the phase records of the HF data for these periods showed no unusual features in the sense that the F-region wave could not be identified. Separation of the ordinary and extraordinary waves could be accomplished by reference to the oblique group height records. That is, the F_2 1-hop mode was, in general, established for the extraordinary wave before it was established for the ordinary wave. One can easily see this behavior by referring to Figure 4, which illustrates the establishment of the 9MHz extraordinary wave group path minutes before the ordinary wave group path is established. The ionogram records and the group path data which is obtained thus provide guidance in interpretation of the phase path data in terms of the particular magneto-ionic mode being received. Mode changes and the amplitude behavior in terms of mode establishment will be discussed in the next section.

Phase path data on the three HF frequencies, 4, 6 and 9 MHz were reduced for the dawn period 1600-2100 GMT and in addition, a detailed minute by minute reduction, was carried out for the 1700-1800 interval on the 18th. These data are illustrated by Figure 7. For example, identification of the modes of propagation and the continuity of the modes,when switching between E and F-modes is taking place, is most easily done when

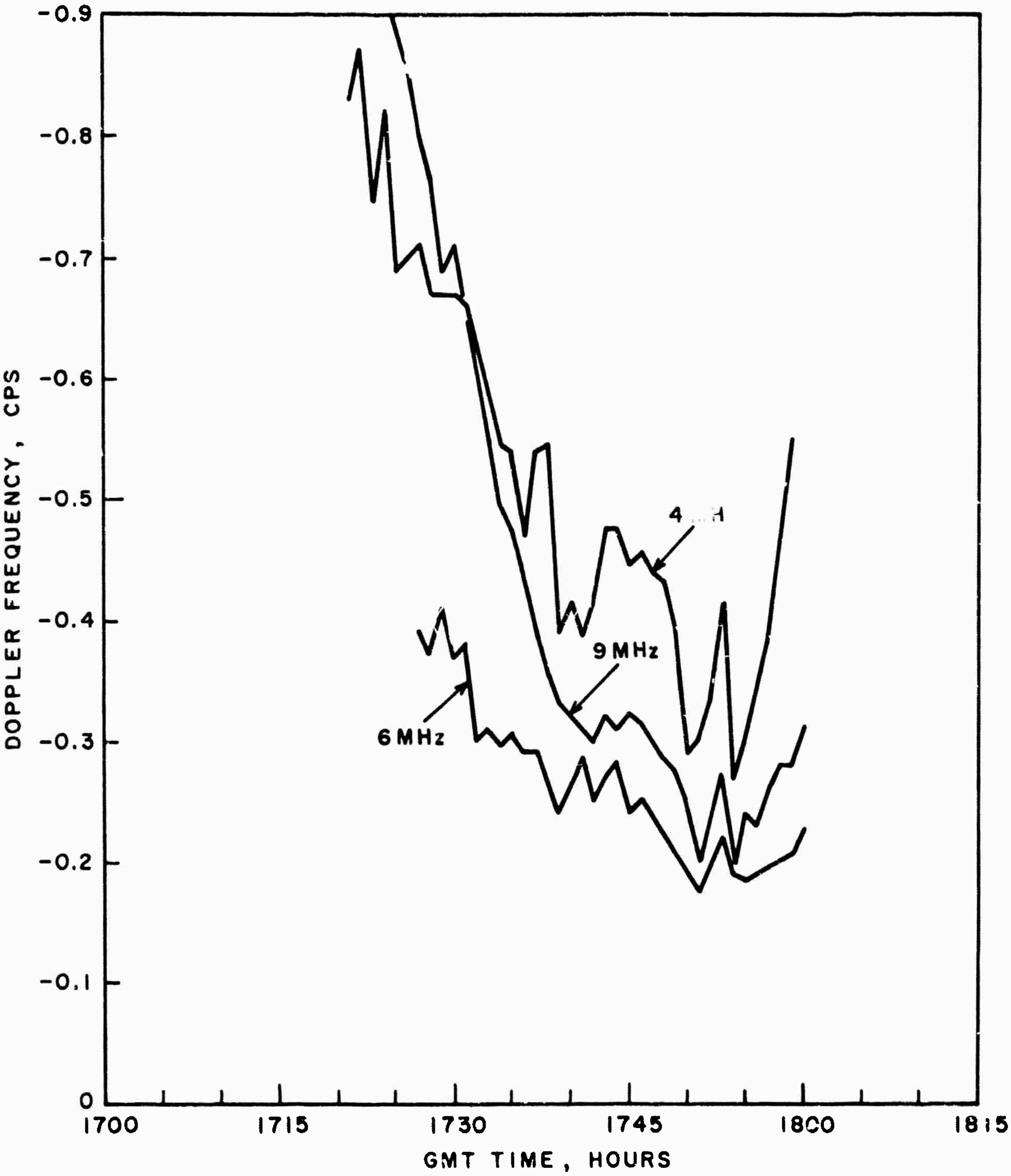

FIG. 7 DOPPLER FREQUENCY, E-MODE
1700-1800 GMT
18 OCTOBER 1962

the data is presented as a Doppler frequency instead of an absolute phase. When the modes are interrupted, the Doppler frequency may be interpolated more easily than the absolute phase; however, the absolute phase record will have an ambiguity of 2 N π radians if the record is interrupted. However the value of N is usually small if the interruption is not long. After mode identification is established and the necessary Doppler interpolations are made, the data may be reintegrated and the relative changes in the phase path of the interval of interest may be determined. This is shown in Figure 8 with respect to the data for the dawn (1700-1800) of the 18th. At this point it is worthwhile to note that no significant periods of loss of a mode were present in this data; therefore no appreciable error is introduced through interpolation of Doppler frequency records through missing data periods.

D. HF Amplitude Data

The amplitudes recorded on the high frequency receivers are typically the sum of a number of mode amplitudes, the ordinary and extraordinary waves of the 1 hop F-mode plus the ordinary wave of the E-mode. The combination of modes is generally not so great in number that a random type of fading pattern is produced. However, careful separation of the effect of the individual modes is necessary in order to determine the

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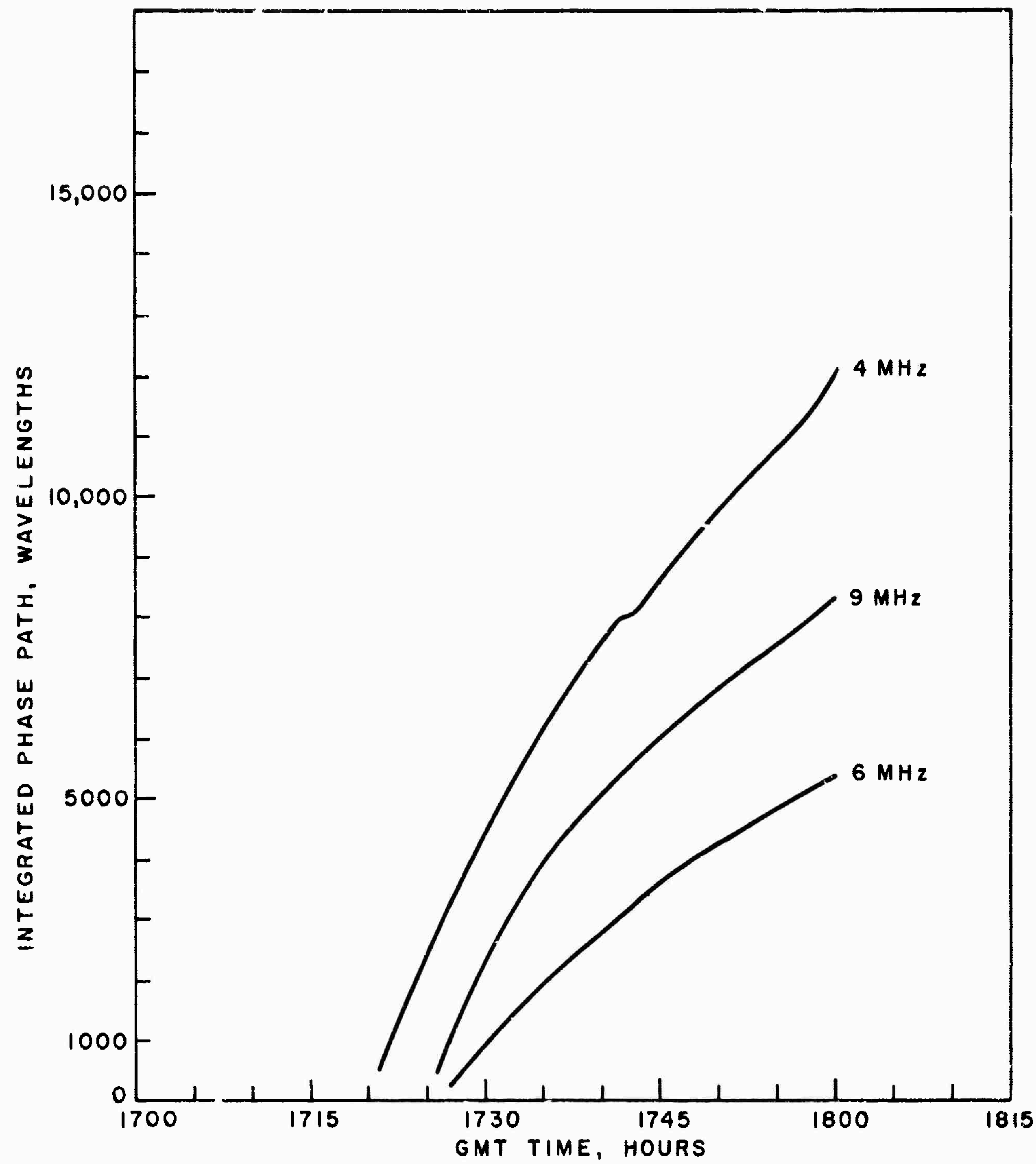


FIG. 8 INTEGRATED PHASE PATH, E-MODE
1700 - 1800 GMT
18 OCTOBER 1962

amplitude of a single mode, which is the quantity required for electron density profile. The fading patterns typically consist of two components: the intermode fading which has a fading rate close to the Doppler frequency of the more rapidly changing mode, and the Faraday rotation fading which usually has a frequency much lower than the Doppler frequency of any of the modes present.

In general, it has been determined that the presence of strong E modes, wherein the Doppler record spends most of the time tracing the E-mode signal, is exclusive to the case wherein Faraday rotation fading occurs in the F-mode. In a practical sense, this is an important exclusion since the fading rates for E-mode interference may be in the same frequency range as those expected from Faraday rotation in the F-mode signal. For most cases mentioned, it will be assumed that the E-mode extraordinary wave is of much lower amplitude than the ordinary wave, and thus will not contribute appreciably to the fading pattern or to the overall signal strength.

Another assumption which may be shown qualitatively is that the Faraday fading depth will be controlled by the presence of the extraneous modes rather than by the antenna pattern. That is, a dipole antenna pattern, even over poor ground, has at least a 10 db null for cross polarized waves. The Faraday fading signal, on the other hand, will not be a strictly linearly polarized wave, although it is the major axis of the ellipse of polarization. Moreover, an important second mode will usually be present.

With the aforementioned assumptions in mind, the analysis of multi-mode fading when both Faraday rotation and intermode fading is present may be illustrated as in Figure 9. The four parameters for this particular fading pattern A_1 through A_4 are related to the three mode amplitudes by the equations:

$$A_1 = S_{fo} + S_{fx} + S_e$$

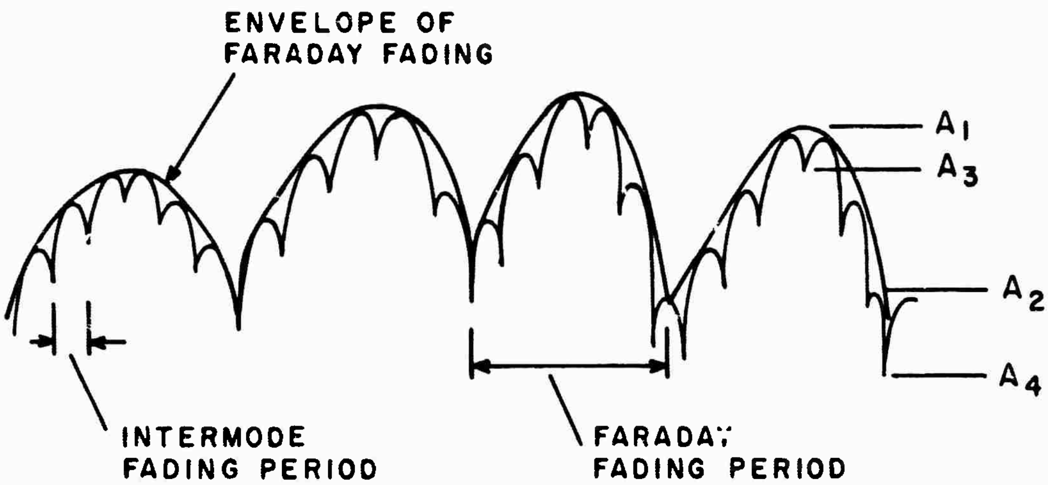
$$A_2 = S_{fo} - S_{fx} + S_e$$

$$A_3 = S_{fo} + S_{fx} - S_e$$

$$A_4 = S_{fo} - S_{fx} - S_e \quad .$$

In many cases the intermode fading pattern will be deeper than the Faraday fading pattern; that is, the major amplitude difference will be between A_1 and A_3 rather than in the envelope described by A_1 and A_2. However, the method of analysis will remain the same.

The results of the combined Faraday and intermode fading analysis are shown in Figure 10, which was given in the first semi-annual report. The values of mode strength will be used later in the analysis of the electron density profile for the period 1700-1800 GMT on October 18th.



$$A_1 = S_{FO} + S_{FX} + S_E$$
$$A_2 = S_{FO} - S_{FX} + S_E$$
$$A_3 = S_{FO} + S_{FX} - S_E$$
$$A_4 = S_{FO} - S_{FX} - S_E$$

FIG. 9 FADING PATTERN FOR SIMULTANEOUS FARADAY FADING AND INTERMODE INTERFERENCE FADING.

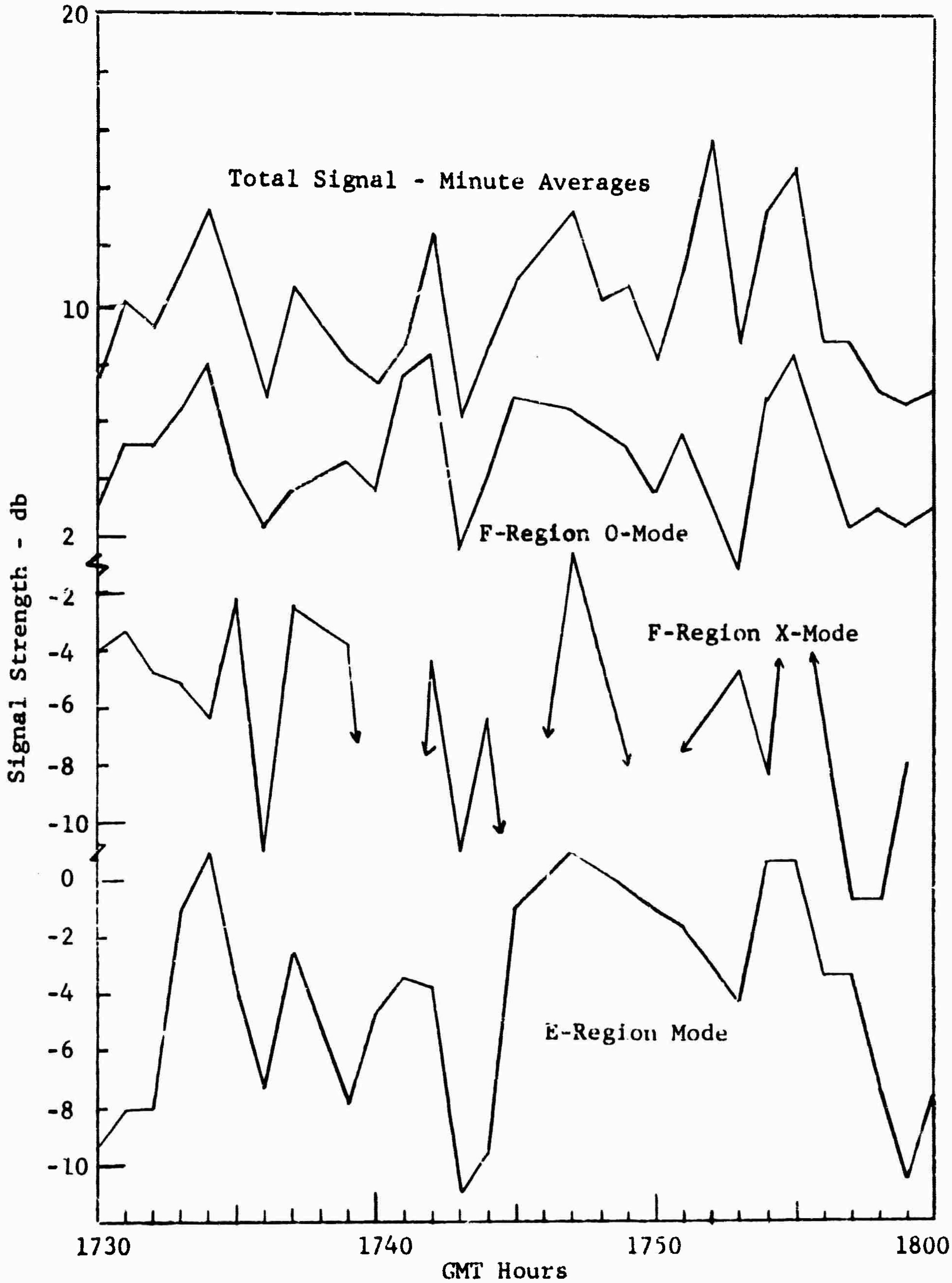


Fig. 10 Signal Strengths of E and F Modes from Faraday Data

III. THEORY

A. Theory - Group and Phase Paths in the Parabolic Layer

A close approximation to the fully developed Chapman layer (x, z 0) is the parabolic layer described by the equation

$$N = N_o (1 - z^2)$$

where z is the reduced height $=(h - h_o)/Y$; h is the actual height, h_o is the height of maximum density, N_o is the maximum layer density, and Y is the layer semithickness = 2H. Rewritten in terms of frequency, the expression is $f_n^2 = f_p^2 \, (1-(z/2)^2)$, where f_n is the local plasma frequency and f_p is the penetration frequency. The group and phase paths for reflection of a high frequency signal within such a layer have been shown to be (Davies, 1965):

$$G = h_o - Y + 1/2 \, Y(f/f_p) \ln \left[(f_p + f)/(f_p - f) \right]$$

and

$$P = h_o - (1/2) \, Y - (1/4) \, Y \, (f_p/f + f/f_p) \ln \left[(f_p + f)/(f_p - f) \right].$$

Of particular interest to this analysis is the separation of group and phase path effects which occur in the deviative

region, the parabolic layer, from the group and phase path effects which occur in the lower ionosphere. The effects may be related to the basic format of data which is used elsewhere in the report, namely the difference between group and phase paths, G-P. This quantity is found from the above equations and is G-P = Y/4. Figure 11 illustrates the variation of the reduced path, (G-P)/(Y/4), as a function of the argument f/f_p. It is clear from the figure that time changes in the quantity G-P, that is, the measured value of G-P at different times will be sensitive to both Y and f/f_p changes. These data will be obtained from ionogram analysis.

A further element of the use of this theory in the analysis is the implicit assumption of the validity of the equivalent group path theory of Martyn concerning the phase path. It may be argued that the phase path changes in the deviative region are a small part of the total phase path change. Thus use of the equivalent vertical frequency as in the group path analysis will be allowable. The error induced by this assumption will be investigated further and an attempt will be made to prove an equivalent statement for phase path.

B. Group and Phase Paths in the Exponential Layer

The lower, non-deviating region of the ionosphere will be approximated by an exponential function,

$$f_n^2 = F^2 \exp\,(az) \quad ,$$

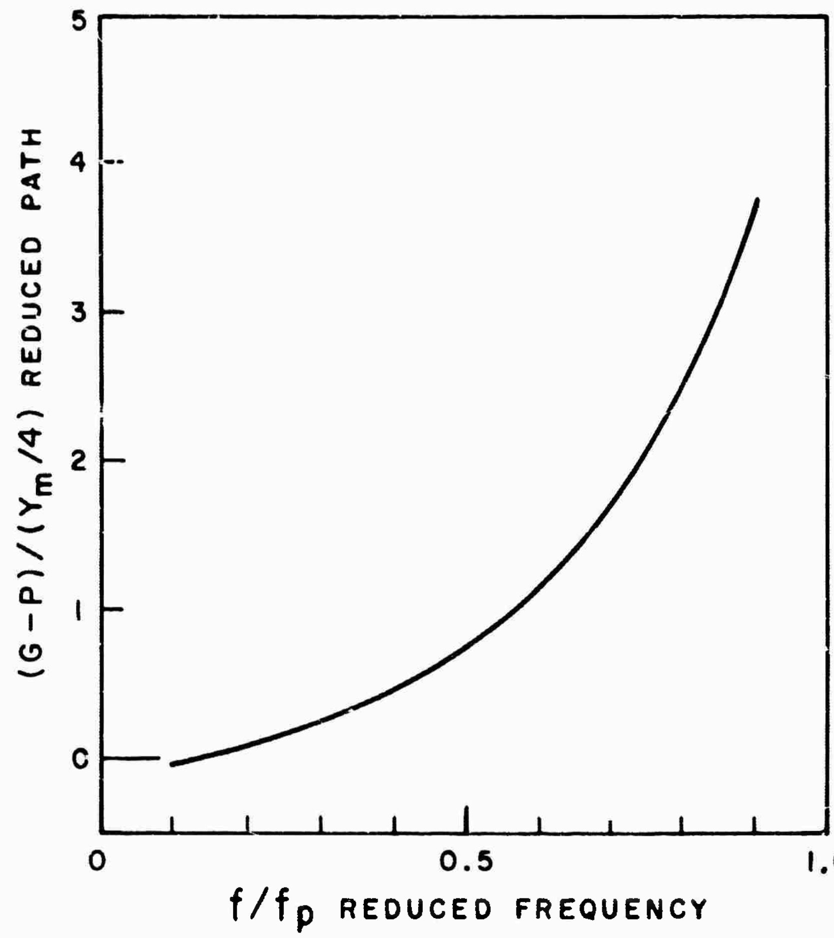


FIG. 11 VARIATION OF GROUP-PHASE HEIGHTS VS FREQUENCY FOR PARABOLIC LAYER REFLECTION.

where z is again a reduced height, F is the plasma frequency at a reference height, and f_n is the plasma frequency at any height in the layer. In all cases in the analysis the transmitted frequency f will be much larger than the highest plasma frequency in the layer so that the layer may be treated as a strictly non-deviating region. Therefore, for this case the group and phase paths are

$$G \simeq 2/a \ \ln \left[f/F + \left\{ (f/F)^2 - 1 \right\}^{\frac{1}{2}} \right]$$

$$P = G - (2/a)(F/f) \left\{ (f/F)^2 - 1 \right\}^{\frac{1}{2}}$$

which become in the limiting case $f \gg F$,

$$G = L$$

$$P = L - 2/a \ .$$

As before, the difference in phase and group paths may be determined as

$$G\text{-}P = (2/a)(F/f) \left\{ (f/F)^2 - 1 \right\}^{\frac{1}{2}} \ .$$

This quantity is plotted in Figure 12 as a function of reduced

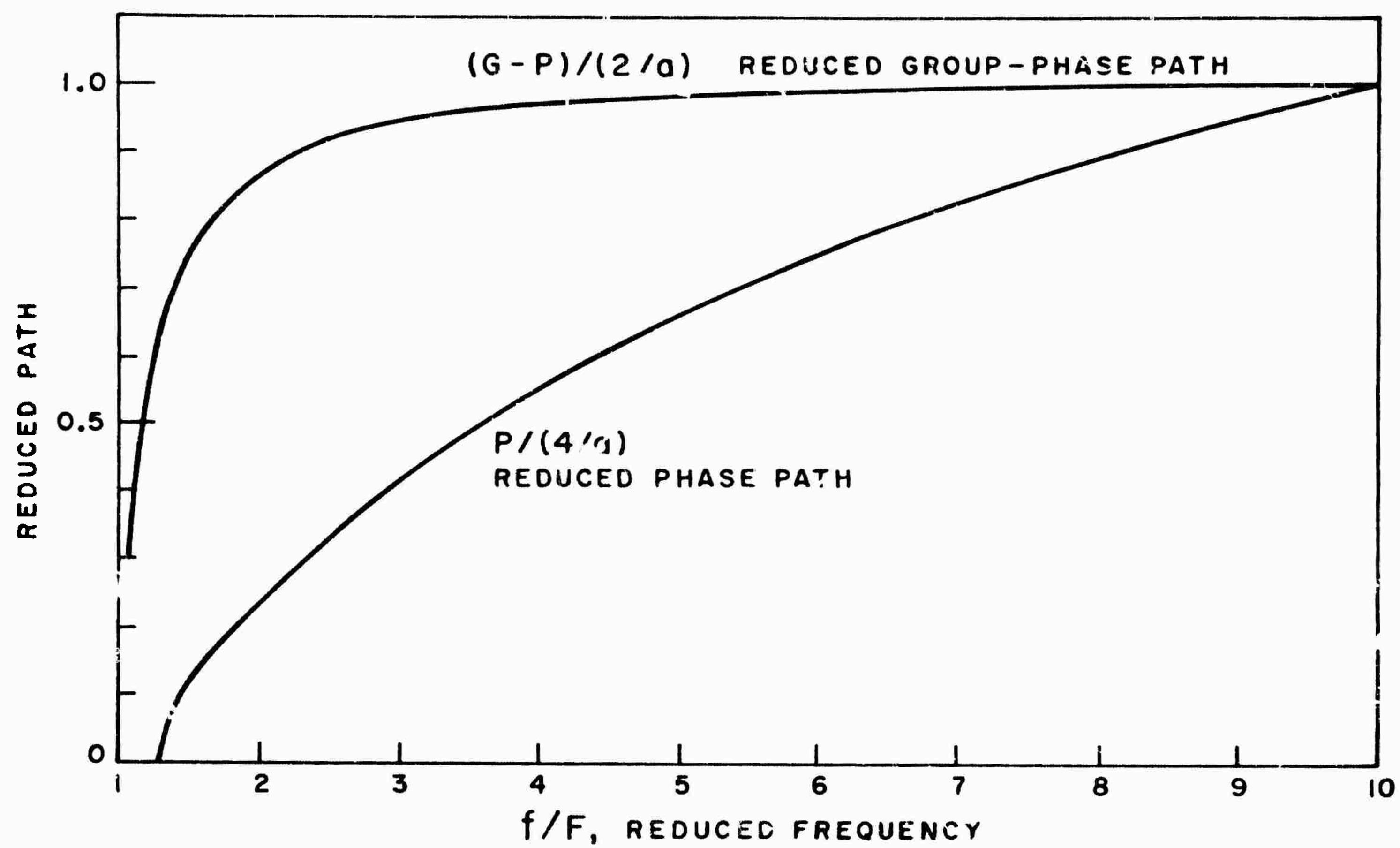


FIG.12 VARIATION OF GROUP AND PHASE PATH VS FREQUENCY FOR EXPONENTIAL LAYER TRANSMISSION.

variables $(G-P)/(2/a)$ and f/F. In this case, $f/F > 1$ is always true.

Of more importance, the actual reduced phase path for the layer is also shown in Figure 12. It may easily be seen that for an equivalent phase path change, the group path change will be a constant factor over much of the frequency range of interest. The magnitude of the group path change will be larger than the phase path change for $f/F \lesssim 3.6$; because of the lack of sensitivity of the ionogram records to wavelength scale changes of path, the phase path will contribute all to the measurable data. The group and phase paths will be assumed to be without deviation over the entire exponential region and the oblique propagation factor will be taken into account by suitable correction of the height terms in the formulation, <u>ie</u> $h(\text{oblique}) = h_v \sec \phi$.

C. Explicit Variations of Layer Parameters

Insofar as the analysis is concerned with defining a change in E-region electron profile description, the parameters of the description are the time variables; that is, the value of a and F will change with time. Thus the sensitivity of the group and phase paths to variations of these parameters must be determined. The following equations describe these

variational terms:

Parabolic Layers

$$\Delta G = \Delta h_o - \Delta y_m \left\{ 1 - \frac{1}{2}\frac{f}{f_p} \ln \left(\frac{f_p + f}{f_p - f}\right) \right\}$$

$$+ \Delta f_p \left\{ -\frac{1}{2} y_m \frac{f}{f_p} \frac{\partial}{\partial f_p}\left[\ln \left(\frac{f_p + f}{f_p - f}\right)\right] - \frac{1}{2} y_m \frac{f}{f_p^2} \ln \frac{f_p + f}{f_p - f} \right\}$$

$$\Delta P = \Delta h_o - \Delta y_m \left\{ \frac{1}{2} - \frac{1}{4}\left(\frac{f_p}{f} + \frac{f}{f_p}\right) \ln \left(\frac{f_p + f}{f_p - f}\right) \right\}$$

$$+ \Delta f_p \left\{ -\frac{1}{4} y_m \left(\frac{1}{f} - \frac{f}{f_p^2}\right) \ln \left(\frac{f_p + f}{f_p - f}\right) + \left(\frac{f_p}{f} + \frac{f}{f_p}\right) \frac{\partial}{\partial f_p} \ln \right\}$$

Exponential Layers

$$\Delta G = -\left(\frac{2}{a^2} \ln \frac{f}{F}\right)\Delta a + \left(\frac{2}{a} \frac{\partial \ln (f/F)}{\partial F} - \frac{f^2}{F^3} \frac{f}{F}^{\,2} - 1^{\,-1/2}\right) \Delta F$$

$$\Delta P = \Delta G - \left\{ \left(\frac{2}{a^2} \frac{F}{f}\left[\left(\frac{f}{F}\right)^2 - 1\right]^{-1/2}\right\} \Delta a$$

$$- \left\{ \left(\frac{2}{a} \frac{1}{f}\left[\left(\frac{f}{F}\right)^2 - 1\right]^{1/2} - \frac{1}{a} \frac{f}{F^2}\left[\frac{f}{F}^2 - 1\right]^{-1/2} \right\} \Delta F \; .$$

IV. DETERMINATION OF ELECTRON DENSITY PROFILES

Phase path data on 4 and 6 MHz were used in conjunction with the parametric description of the parabolic layer outlined in the previous section to determine the electron density profile for certain times between 1720 and 1800 GMT on 18 October 1962. The data utilized for this analysis was described in Section II and the true height analyses of ionograms taken at simultaneous times were utilized to determine the plasma frequency or altitude of the upper boundary point of the layer. In many cases, when only the observed E-region plasma frequency was used, the peak height parameter h_o and the thickness parameter Y became too large. This is because the electron density near the peak of the E-region is better represented by the parabolic layer description than the density near the respective reflection points for the 4 and 6 MHz waves. However choice of a layer height parameter h_o, from the true height analyses, allowed computation of a realistic thickness parameter, Y, from both sets of data.

The electron density contours computed from the parabolic layer approximation and application of only the plasma frequency at the peak of the parabola are illustrated in Figure 13. It may be seen that agreement of the computed profiles from the true height profiles obtained from ionograms becomes poor as the computations are repeated and carried backwards in time from

the 1759 profile. This backward computation was carried out instead of a forward time method because the 1759 profile appeared to be the best known. The direction of the time or iteration interval is immaterial since the phase and amplitude data can be carried either way from a reference point. The profile comparison made at 1759 resulted from fitting the three parameters h_o Y and f_p to the ionogram derived true height curve. Thus it would be expected that the three curves, 1759, 1750 and 1740 would agree quite well with the ionogram results. This is not the case and as mentioned before, results from the sensitivity of the computation to the exact choice of h_o.

Before moving on to more accurate techniques of fitting the profiles, it must be emphasized that the failure of the initial attempt is not in the method but in the extension of the profile from where it fits in the 4 and 6 MHz region to where it is forced to fit the ionogram profile results at higher altitudes. In each case this region of joining is appreciably above the altitude of the 4 and 6 MHz reflection altitude. Therefore, if the contour as initially derived is considered to be that applicable mainly to the 4 to 6 MHz region, it will be quite representative. The goal, however, is to produce a continuous contour which will extend the ionogram derived density contour downwards in an accurate fashion.

In order to better fit the results of the hf analysis with the true height contour, the parameter h_o is varied and the profile fit is examined. Figure 14 shows the effect of variation

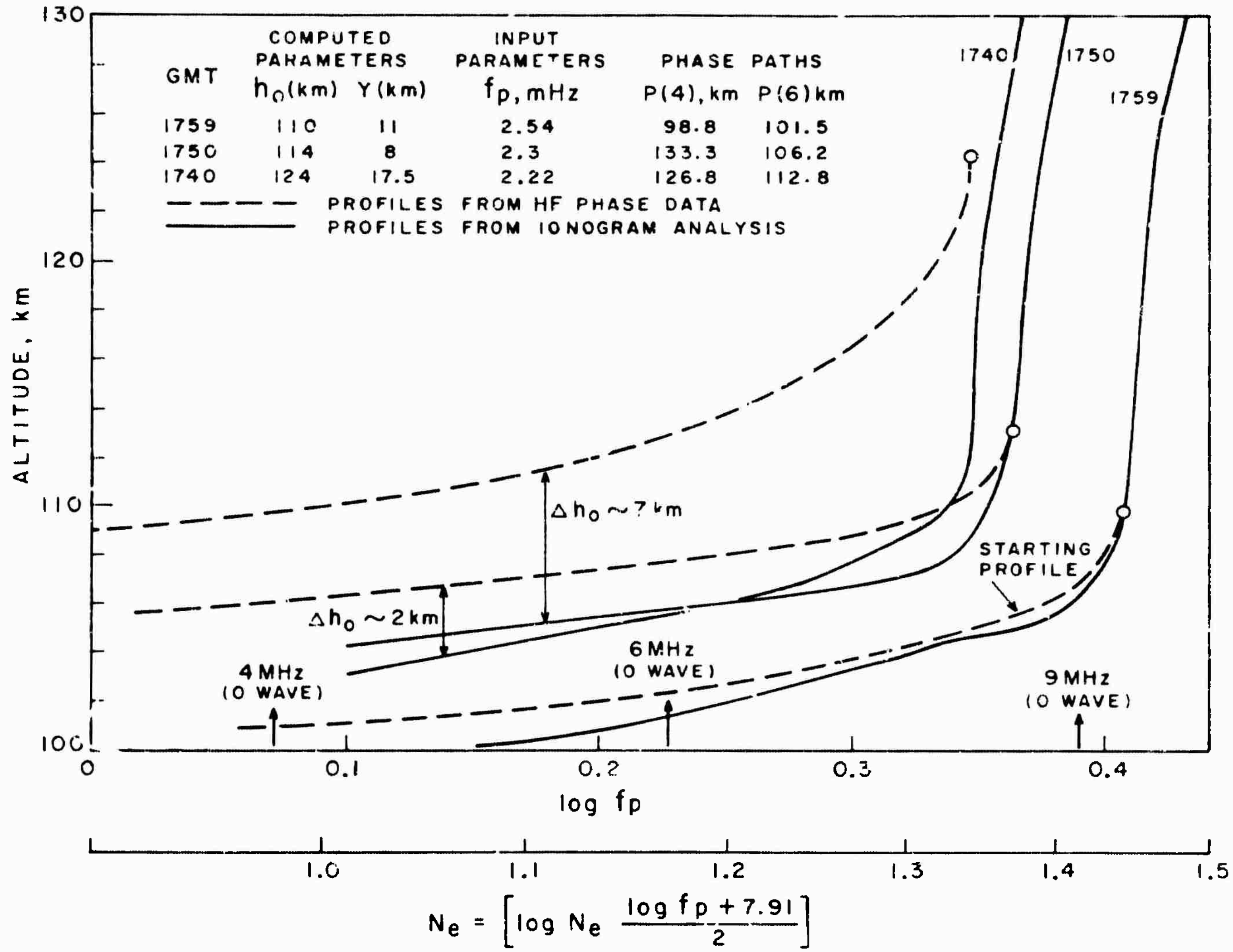


FIG. 13 COMPARISON OF TRUE HEIGHT PROFILES WITH SINGLE PARAMETER, f_p, RESTRICTION.

of h_o on the 1720 GMT profile. It may be seen that the layer thickness which is most comparable to that expected from the other data also corresponds to the best fit of the true height curve.

In conclusion, since the desired results are the description of the ionosphere at heights or densities below those amenable to true height analysis, the best ionogram and hf true height curves are presented in Figure 15.

One qualifying note must be added: the matching region of the hf and ionogram true height curves depend upon the accuracy of the ionogram true height analyses for the initial or starting point of the analysis. Thus, the quality of the hf true height profiles will depend directly upon the quality of the ionogram true height profiles and hence will possess some degree of ambiguity. However, use of the amplitude data will impose additional altitude constraints on the profiles and will aid in fixing lower boundary conditions just as the ionogram results are used for upper boundary conditions. It was impossible to apply this extended analysis to this time period because no 4 or 6 MHz amplitude data were obtained because of equipment difficulty.

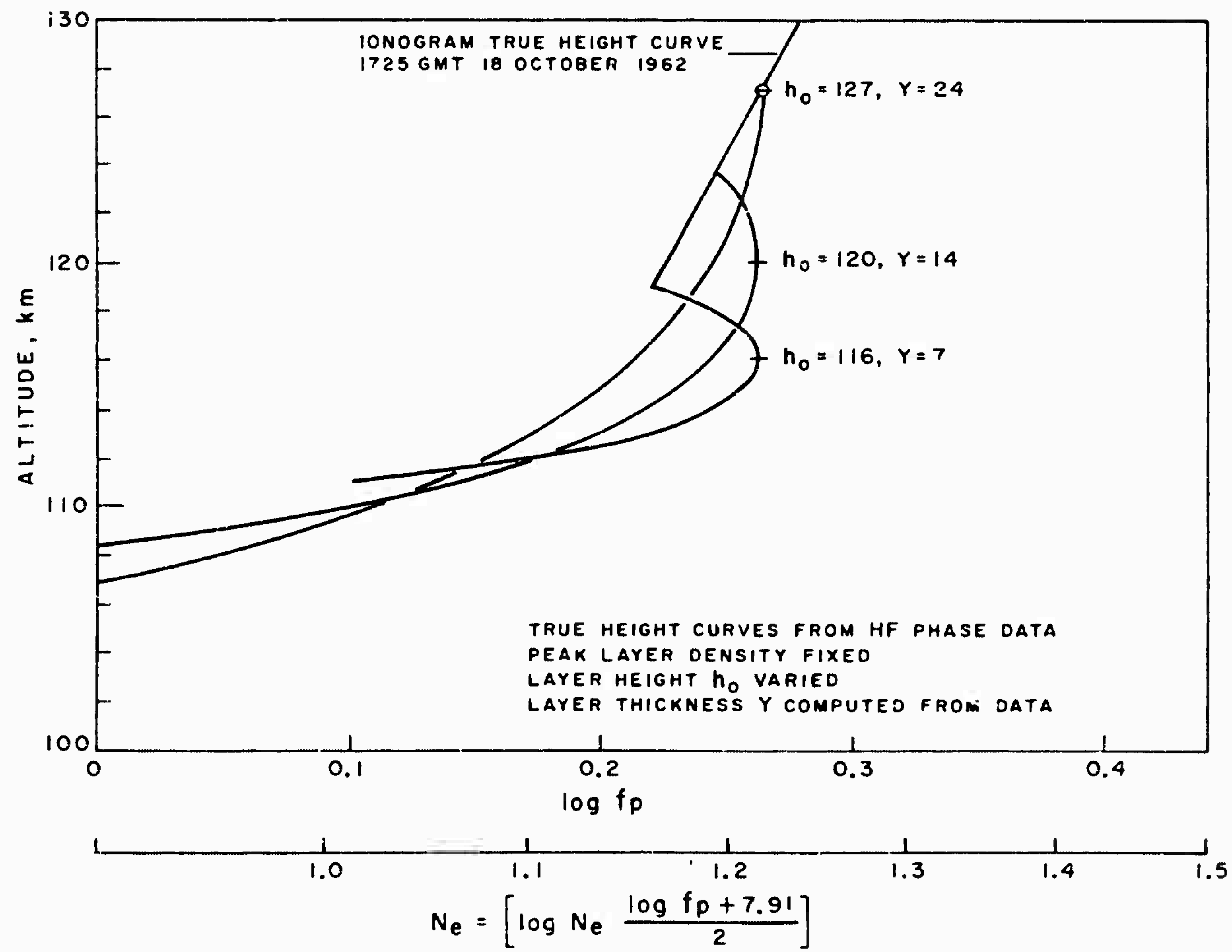


FIG. 14 EFFECT OF VARIATION OF HEIGHT PARAMETER ON PARABOLIC ELECTRON.

V. IONOSPHERIC DISTURBANCE CHARACTERIZATION FOR ALL DATA PERIODS

Data records from two intervals were obtained in the South Pacific sites during the 1962 test series. The first period was in the spring and good data was obtained from July 4 to 11 and from July 21 to 26. In the fall, a few days data were obtained in September; however most of the useable data covered the period 15 October to 5 November. The data chosen for initial examination for this analysis was in the 15 October to 20 October interval.

It is desirable to characterize the degree of solar, geomagnetic and ionospheric disturbance for the days in which data were obtained so that a representative choice of analysis periods can be made. In particular, the differences in the statistical, or short term, phase and amplitude variations in the HF data between high ionospheric disturbance days and normal or quiet days is an important factor to be examined during the second phase of the study.

In order to allow this selection, the worldwide geomagnetic disturbance index K_p, the solar radio noise index S, and the existence of solar flare activity are tabulated in this section. In addition, the acquisition index numbers of the appropriate data are listed in order to allow ease in locating particular samples of data.

Examination of the tables will indicate that the period of detailed ionospheric profile analysis (1700-1800 GMT, 101862) corresponds to one of the two opportunities present during the entire experiment to measure the ionization produced by a solar flare. Unfortunately the flare took place during early morning and thus the full effects at lower altitudes were probably not realized because of the grazing incidence of the x radiation.

TABLE A

SOLAR DISTURBANCE INDEX GEOMAGNETIC DISTURBANCE INDEX
FOR JULY AND DATA REFERENCE

Date	S(1)	Sum K_p(2)	Tut.ABS	Tonga ABS	HF4	HF6	HF9
1		18		1118			
2		15q		1118			
3		16q		1118			
4	90	25D		1118	1189	1187,91	1186
5	88	24D		1118	1188,93	1192	
6	86	21		1118			1185
7	88	15		1118	1195	1194	1190
8	83	20		1118	1198	1200	1202
9	80	12Q		1118	1197	1196	1203
10	81	15		1118	1199	1201	1204
11	83	18	1140-1	1141	1206	1205	1207
12	82	15q	1451	1141			
13	86	19	1451	1141			
14	86	17	1451	1141			
15	85	11q	1451	1141			
16	84	6Q	1451	1141			
17	84	4Q	1451	1141			
18	82	8Q	1451	1141			
19	80	18	1451				
20	80	24	1451				
21	79	21	1451		1519	1518	1517
22	80	14q	1451		1519	1518	1517
23	78	16	1451	1412	1523	1522	1521
24	78	20	1451	1413	1527	1526	1525
25	74	20	1451	1413	1527	1526	1525
26	76	37D	1122	1413	1531	1530	1529
27	74	31D		1417			
28	74	26D		1417			
29	73	17		1425			
30	72	10Q					
31	73	15					

1. Data is daily values of solar flux at 2800 MHz in units of $10^{-22} Wm^{-2} hz^{-1}$ taken from "Handbook of Geophysics and Space Environments" ed. S.L.Valley, McGraw Hill, 1965.

2. Data is Sum K_p index value from J. V. Lincoln, J. Geophys. Res. 67, 4875, 1962. Q and D indicate 5 selected quiet or disturbed days, q and d indicate 10.

3. Accession numbers correspond to those in the ionospheric data catalog at IIT Research Institute.

TABLE 8

SOLAR AND GEOMAGNETIC DISTURBANCE INDICES FOR OCTOBER-NOVEMBER DATA

Date	S(1)	Sum K_p(2)	Tut. ABS	Tonga ABS	HF4	HF6	HF9
October							
13	95	18q	2228	1576	2269	2270	2268
14	95	33	2228	1576	2269	2270	2268
15	94	18Q	2228	1576	2272	2273	2274
16	91	25	2228	1588	2288	2287	2286
17	91	13Q	2228	1588	2275,92	2276,91	2277,90
18	89	22	2387	1588	2280,96	2278,95	2279,96
19	87	27	2387	1588	2280	2278	2279
20	88	19q	2387	1588	2284	2283	2282
21	87	22	2387	1588	1914	1913	1912
22	85	29	1656	1588	1914	1913	1912
23	84	29	1656	1588	1919	1916	1917
24	89	31	1656	1977	1922	1921	1920
25	87	35D	1656	1977	1922	1921	1920
26	87	34D	1762	1977	1842	1850	1841
27	86	31	1762	1884	1845	1844	1843
28	82	26	1762	1884	1845	1844	1843
29	80	22	1762	1884	1849	1848	1847
30	82	23	1762	1884	1854	1853	1852
31	81	1[illegible]Q	1762	1884	1858	1857	1856
November							
1	80	16	1762	1888	1866	1865	1864
2	80	22	1762		1894	1893	1892
3	90	23	1659	2157	1894	1893	1892
4	82	26	1659	2157	1901	1900	1899
5	82	11q	1659	2157	1901	1900	1899

1. Data is daily values of solar flux at 2800 MHz in units of 10^{-22} $Wm^{-2}hz^{-1}$ taken from "Handbook of Geophysics and Space Environments" ed. S.L.Valley, McGraw Hill, 1965.

2. Data is Sum K_p index value from J.V. Lincoln, J. Geophys. Res. 67, 4875, 1962. Q and D indicate 5 selected quiet or disturbed days, q and d indicate 10.

3. Accession numbers correspond to those in the ionospheric data catalog at IIT Research Institute.

TABLE C

SUMMARY OF SOLAR FLARE ACTIVITY

Date	Beginning Time	Ending Time	Importance
July			
5*	1937Z	1947Z	2
8	1540Z	1604Z	1+
October			
15	1525Z	1550Z	1+
16	1000Z	1038Z	1+
17*	0717Z	Not Obs.	1+
18*	1705Z	1730Z	
20	1625Z	Not Obs.	1+
21	1535Z	1645Z	1+
23	1705Z	Not Obs.	1+
23	1642Z	1745Z	2
24	1306Z	1346Z End Not Obs.	1+
28	1751Z		Microflare

*Indicates flares which could be observed from the Pacific low latitude sites.

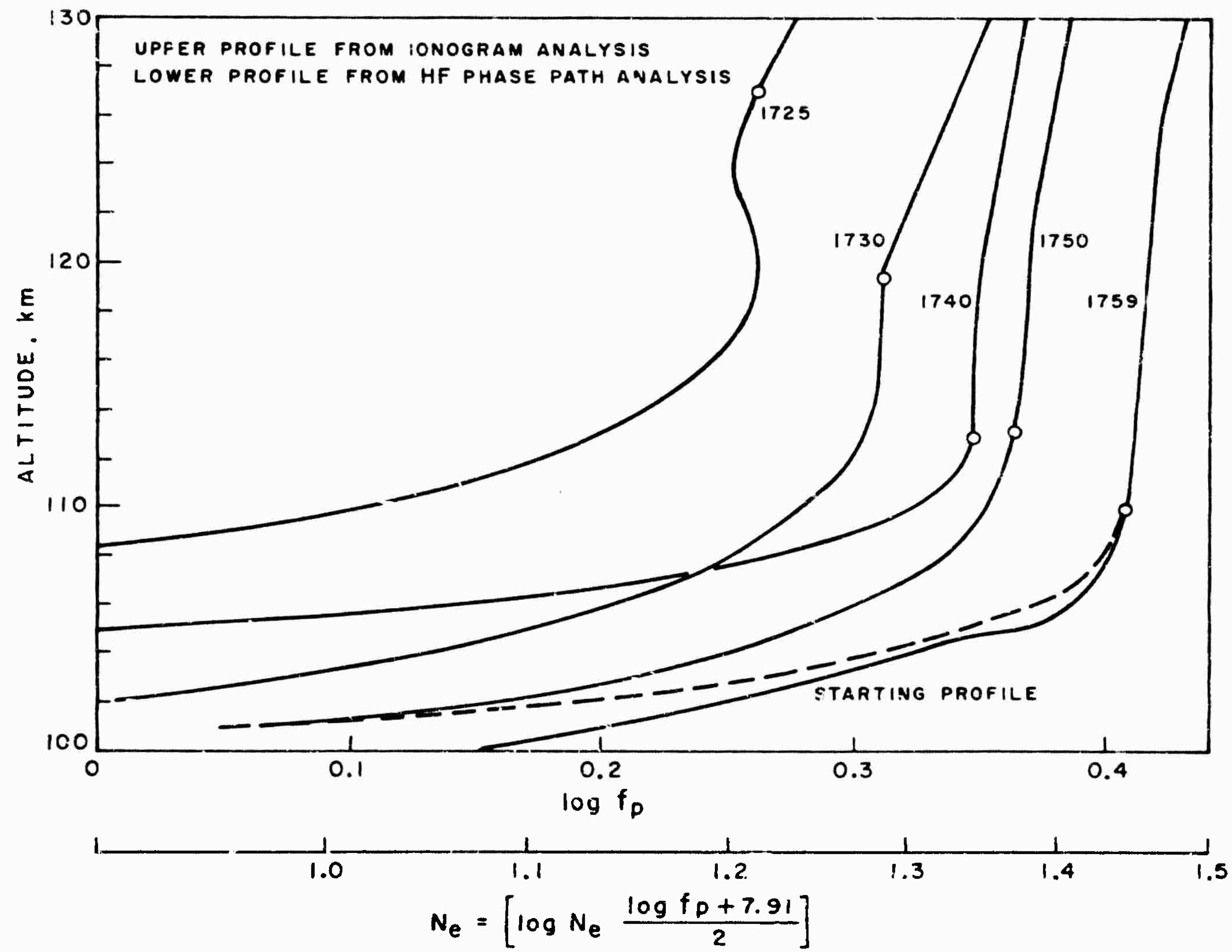


FIG. 15 ELECTRON DENSITY PROFILES FOR 18 OCTOBER 1962, 1725 TO 1800 GMT.

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APPENDIX A

ERROR ANALYSIS OF GROUP AND PHASE PATH ANALYTICAL APPROXIMATIONS

In analysis of the down increase in ionospheric electron content, the quantity

$$P-G = \int \left(\frac{1}{\mu} - \mu \right) d\,p$$

is derived from experimental data. The group path is obtained by reduction of ionogram records and the phase path is determined by hf phase measurements. In order to determine the possible error in excess phase path change, i.e. that part of the phase change determined by the lower ionospheric electron density profile changes, the error in group path measurements, phase path measurements and the analytical theory must be determined.

Measurement errors and the error induced by data reduction techniques in the virtual group path data, G, are estimated to be $\Delta G = \pm 2$ km. This is equivalent to $\pm 26\lambda$, $\pm 40\lambda$, and $\pm 60\lambda$, at 4, 6 and 9 MHz respectively. This error includes both the geometrical path error and that induced by wave retardation. The down period F mode is characterized by many cycles phase change so with a phase error of ΔP ± 1 cycle, $\Delta P/p < 1/p$, and thus the relative error is small compared with

the $\Delta G/G \pm 2/G$ value as long as P is great enough. For this reason, the time intervals covered by the measurements are made large enough to ensure that $1/P$ and $2/G$ are small.

Errors may be induced by the approximate expression chosen for the value of $\mu = (1 - X)^{1/2}$. For example, if the non-deviative approximation is adopted, $\mu = (1 = 1/2\ X)$, and the expression may be in error in the reflection region.

The quasi-longitudinal case is studied herein by expanding the function $\mu = (1-X)^{1/2}$ to the third power, then evaluating a perturbation imposed at the largest usual value of X. That is, the expression $(\mu \pm \Delta\mu)$ is evaluated at $X = 1/2$, its largest nominal value for F-mode reflection. Thus $\mu(\min) \leq 0.7$. The ionogram true height analyses were evaluated for all three frequencies in the period 1700-1800 on October 18 and others which were available were examined. In most cases the value $X = f_o/F \leq 0.5$.

The expansion of is:

$$\mu = \mu_o + \mu_o' + \frac{1}{2!} \mu_o'' X^2$$

$$\mu = 1 - \frac{1}{2} X + \frac{1}{8} X^2 - \frac{1}{48} X^3 \quad \text{etc.}$$

$$\frac{\mu \text{ 1st order}}{\mu \text{ true}} = \frac{0.75}{0.7} = 1.07$$

Thus, use of the quasi-longitudinal non-deviation index of refraction induces at most an error of a few percent in the phase path relationship to integrated electron content.

The group path error is also of interest but will not enter strongly into the error of the analysis because the group path effect is subtracted from the data and is not used specifically in analytical form

$$\frac{1}{\mu} = (1 - X)^{-1/2} = 1 + \frac{1}{2} X + \frac{3}{4} \quad \frac{1}{2!} X^2 - \frac{15}{8 \times 3!} X^3$$

$$\frac{1}{\mu} \text{ at } X = \frac{1}{2} = 1.42 \quad \text{and}$$

$$\frac{\mu \text{(1st order)}}{\mu \text{ (true)}} = \frac{1.25}{1.4} = 1.12$$

A 12 percent induced error is present in the first order approximation to the group path analysis if group path data were to be analyzed in this fashion.

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13. ABSTRACT A technique for determining the electron density profile in the E-region from group path, phase path, amplitude and true height analysis data is described. A selected data period, 1600 to 2100 GMT on 15 to 19 October, is summarized in the detailed reduction and analysis of the individual data obtained from the different measurement techniques. One period of detailed electron density profile computation is presented. The period 1700 to 1800 GMT on October 1962 also included a moderately intense solar flare so that the excess ionization caused by the flare in the lower ionosphere may be observed. The true height analyses which are developed are extensions of the true height analyses of the F-region and serve to extend conventional true height analysis to lower altitudes or lower electron densities than possible from the conventional analyses alone.

The data were obtained utilizing ionosondes, a three frequency HF propagation measurement of both phase and amplitude and riometer measurements of cosmic noise absorption. To develop the profiles presented herein, the group height records from ionograms and phase height measurements from the HF experiment were used.

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